COMBAT RATION ADVANCED MANUFACTURING TECHNOLOGY DEMONSTRATION (CRAMTD)

"Non-Destructive Prototype to Inspect MRE Pouch Seal Integrity"

Short Term Project (STP) #21

FINAL TECHNICAL REPORT
Results and Accomplishments (May 1994 through September 1995)
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DEFENSE LOGISTICS AGENCY
8725 John J. Kingman Road
Ft. Belvoir, VA 22060-6221

Contractor:
Rutgers, The State University of New Jersey
THE CENTER FOR ADVANCED FOOD TECHNOLOGY*
Cook College
N.J. Agricultural Experiment Station
New Brunswick, New Jersey 08903

Principal Investigators:
Mr. Neal Litman and Prof. Kit Yam

Dr. John F. Coburn
Program Director

TEL: 908-445-6132
FAX: 908-445-6145

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N. Litman and K. Yam

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Rutgers, The State University of New Jersey
The Center for Advanced Food Technology
Cook College, N.J. Agricultural Experiment Station
New Brunswick, NJ 08903

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Laboratory and plant-floor testing was conducted on three methods proposed as candidate approaches to leak detection in MRE pouches: (1) a pressure method which would be applied while pouches are still in the horizontal form/fill/seal machine, (2) a vacuum method using decay of chamber pressure as the indicator of leakage, and (3) a vacuum method using package expansion as an indication of a leak. The pressure method was found to have severe difficulties with the proposed integration with the horizontal form/fill/seal machine (necessary to its application to MRE pouches) and was therefore rejected. After a number of modifications, the accuracy of the vacuum/pressure decay method remained below that of the vacuum/package-expansion method (45% vs 72%). It was recommended that further development be carried out using the vacuum/package-expansion method (commercially available device sold as an "ATC-3 Electronic Package Tester").

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Contents

1.0 CRAMTD STP #21

Results and Accomplishments

1.1 Introduction and Background

The objective of STP #21 was to develop a preliminary design of a prototype machine to perform non-destructive inspection for leaks and weak seals for MRE pouches. This prototype was based on the knowledge learned from STP #7, "On-Line Inspection and Testing Method for Pouch Integrity." This project establishes feasibility of integration and hardware requirements for installing inspection equipment on-line.

The inspection techniques currently in use for packaged food manufacturing are not capable of rapidly detecting many package defects that occur in the typical manufacturing process including combat rations. Of particular concern is the continued reliance of inspection methods that include on-line human inspectors and off-line statistically based destructive methods. The existing approach is questionable in terms of cost, ability of finding defective packages and potential for creating defects by pouch handling. Therefore, an effective automated on-line non-destructive inspection system would have enormous benefits to the packaging operation.

Presently there is no commercially available non-destructive, on-line machine for 100% inspection of MRE pouches. STP#7 identified two techniques that may be used; external pressure and vacuum test method, and which formed the starting point for this project. In a presentation to the Institute of Packaging Professionals entitled, "Pressure Differential Techniques for Package Integrity Testing" (Appendix 4.2), Dr. Yam described these techniques.

The scope of this project (STP #21) included feasibility of implementing on-line non-destructive pouch inspection system, determine the most cost effective solution, design/develop and fabricate a prototype device, demonstrate the prototype system and develop specifications for a commercial version. The project was conducted in two phases: review of methods including testing and fabrication/assembly/test (Appendix 4.1).

1.2 Results and Conclusions

Pressure Method

Investigations based on pressure methodology were conducted on a device supplied by Container Integrity Corporation (Appendix 4.3). This test method is based on inflating, with high pressure air, a channel created by clamping the top and bottom web together outside the perimeter of the pouch seal. Since the exterior side of the seal is stressed during the test, there is no damage to the critical interior heat seal interface. The method has potential for detecting very small and weak seals.

The experimental design attempted to quantify the detectable defect level and characterize tester parameters. In laboratory controlled conditions, many defects were readily detected.

Channel leaks of approximately 50 micron or less were in most tests self sealing and therefore undetected. For example, a test pressure of 200 psi (maximum allowed on CIC unit) exerts the equivalent stress. A correlation between *external air pressure applied* to the internal pressure test method most commonly used to determine seal strength resulted in a ration of 20:1, i.e. the CIC test pressure of 200psi was equivalent to 10psi by the internal pressure method. The CIC unit was limited to 200psi and therefore the tester was capable of detecting very weak seal only. Processors typically test pouches to 30psi prior to retort. Design and operation of machine requiring very high air pressure is clearly a challenging problem. The results however showed a large variation which was discovered to be related to maintaining consistent channel width and package alignment within the tester chamber. Channel width on the Tiromat horizontal form/fill/seal machine varies from .25" to nil. The CIC unit was evaluated for affects of machinery vibration, and was found to require additional sensor equilibrium time. In the worst case, the sensor was not able to stabilize with ambient machinery vibration. Under the most optimum conditions, the tester was able to make a defect determination within 2.5 seconds, the maximum amount available during the Tiromat dwell. This would have a significant detrimental impact to overall line production rate. The pressure method was therefore found to have severe difficulties for integration with horizontal form-fill-seal packaging equipment.

Vacuum Method

The vacuum method subjects the package to vacuum pressure which expands the internal gas. By restraining the MRE, a higher pressure is created inside the pouch (differential pressure) which can draw gas or liquid through a hole in the seal or pouch body. A sensor detects a change in the test chamber pressure (pressure decay) or measures the expansion of the container. Several companies build testers based on this method, however detection strategies vary by system (See Appendix 4.4). Of these, testers from Packaging Technologies & Inspection, Inc. (PTI) and Applied Technology Concept, Inc. (ATC) were evaluated at CRAMTD. Testers of this type have been designed for 100% on-line inspections. Vacuum leak detectors can be used at a number of locations within the plant; after pouch sealing, after retort and after cartoning.

PTI

Packaging Technologies & Inspection, Inc. (PTI), an equipment supplier in the area of leak detection, tested sample MRE pouches on their Wilco vacuum tester (Appendix 4.5). This unit is PLC controlled and measures the decay of vacuum pressure in the chamber with high sensitivity pressure transducer. A significant decay indicates leakage from the package into the test chamber. The initial PTI results suggested detection of leaks was possible. A larger scale test included fabrication of custom tooling for the MRE pouch. Several tooling designs were evaluated; rigid pouch confirming chamber and a flexible membrane chamber. The rigid chamber detected defects when pouches had significant headspace (>25cc residual gas) and the hole was large. The flexible chamber was able to detect smaller holes but required excessive residual gas and had difficulties when defects were located on the bottom of the pouch. In benchmarking trials with MRE pouches of less than 10cc residual gas, the Wilco unit accuracy

dropped significantly.

ATC

A second vacuum test unit from Applied Technology Concepts was evaluated concurrently with the PTI unit. This unit is designed to maintain a constant chamber vacuum level (regardless of leakage) and measure package expansion using a linear voltage displacement transducer (LVDT). This system employs a PC based data acquisition system and sophisticated algorithms to evaluate the container expansion. See appendix 4.6 for description of this system.

Results of performance tests in which the Wilco and ATC testers were evaluated simultaneously are reported in Appendix 4.7. The ATC unit accuracy was significantly higher (72%) than the Wilco unit (45%). The Wilco unit was considerably faster, however either unit could be adapted to on-line production rates. Both units perform well when pouches contain large headspace.

A series of tests were conducted at the MRE producer AmeriQual Foods to verify CRAMTD pilot plant results for the ATC-3 tester. Chicken Stew pouches were taken directly from the production line at several locations. Despite best efforts by CRAMTD personnel and the inventor of the ATC-3 unit, a baseline set up could not be established. No useful data from production pouches was made. Differences in production processes of AmeriQual vs. CRAMTD were the cause.

1. Uncontrollable pouch expansion (product flash) due to hot fill.
2. Very low residual gas (typically less than 1cc) due to steam flush evacuation.
3. Extremely low defect rate - 1 actual leaking pouch in approximately 80,000 produced.

Pouch leaks were not produced during production in significant numbers to establish leak tester accuracy. In discussions with production personnel, leaks when produced are usually punctures caused by handling and can occur at any point of production. The most probable locations are; loading retort racks, retort racks during thermal processing, unloading racks, final inspection, cartoning. Based on this processor experience, the location of leak detection equipment should be just prior to or after the cartoning operation.

Grilled chicken breast MREs taken from AmeriQual warehouse inventory were tested in the ATC unit for leaks (produced artificially). Leakers were detected at 88% accuracy, both in and out of the carton. These pouches were tested at ambient temperature (72°F) and had residual gas levels of approximately 7cc. This result is consistent with pouches tested at CRAMTD.

The results for the ATC-3 leak tester were compiled and Benchmarks (Appendix 4.8) were established. The results clearly indicate a strong correlation with residual gas levels, pouches with very low residual gas are not candidates for leak detection. Unless residual gas levels are controllable and near the upper MIL-SPEC limit of 10cc, the vacuum leak detection method will not be reliable. HFFS machines producing pouches using vacuum/seal can accurately control residual gas level to 7-10cc and will therefore be more suitable for this type of leak detection.

1.3 Recommendations

Pressure Method

The pressure method for on-line inspection of MRE pouches was eliminated from further consideration as being impractical for the following reasons:

- only inspects pouch seals, visual inspections before and after retort still needed
- very high risk to develop working prototype
- cannot test pre-formed/vertical filled pouches
- high equipment cost> $300,000 per line, negligible benefit

The external pressure test is not an appropriate method for testing pouch integrity of MRE pouches, however it may be applicable to tray seals for the military half steam table tray or the prototype polymeric half steam table tray. An investigation should be made to determine whether seam or seal leakage is a significant problem for military trays. If a problem exists, a study to determine feasibility of integration of pressure method leak detection should be undertaken.

Vacuum Method

Vacuum method leak detection systems have demonstrated success under some conditions, especially pouches produced on HFFS equipment. Baseline operating parameters should be developed for the ATC-3 tester for hot filled steam flushed pouches and benchmark performance established.

Perform a detailed analysis of USDA/AVI inspection data to categorize and determine the actual production defect level for each type of leak defect. Establish human inspector efficiency. Develop an inspection strategy based on automated leak detection equipment that has a higher inspection efficiency than human inspection thereby reducing defects. The inspection strategy should consider various possible inspection locations within the pouch processing system eliminating one inspection and reducing pouch handling (further reducing pouch defects).

Evaluate ATC-3 tester for non-destructive measurement of residual gas. Preliminary data suggests that this may be a useful method in an SPC program for pouch residual gas.

2.0 Program Management

This program will be conducted in two phases. As control at the conclusion of Phase I, a management review will be held to determine the steps to be taken in Phase II. Phases, management review and completion time are shown on the CRAMTD STP #21 Program Planned Schedule (Appendix 4.1).

Phase I: Review entire methods, develop concepts, determine critical areas through testing, preliminary engineering, and make recommendations, supported by documentation of alternatives, comparisons and rationale used to arrive at the final recommendations.

Phase II: We will contract to have the prototype components and devices fabricated and assemble the equipment. Tests will then be performed to determine performance and/or adjust the design.

2.1 Progress Summary

- Feasibility study concluded the pressure method not feasible for on-line inspection on the Tiromat HFFS packaging machine.
- Attended pharmaceutical Interphex Exposition where contact was made with several companies offering non-destructive leak testing equipment.
- Packaging Technologies & Inspection was contracted to fabricate tooling and perform tests with their vacuum leak detection equipment.
- PTI Wilco leak tester unit was tested on MREs in the CRAMTD pilot plant. Detectability of leaks was below 50% with headspace below 10cc residual gas.
- ATC-3 leak tester was leased in June to conduct evaluations at CRAMTD. Results indicate that 72% leak defects were detected.
- Hosted DPSC Leak Detection Initiative meeting, demonstrated ATC-3 unit.
- Conducted plant trial at AmeriQual Foods with ATC-3 leak tester.
- Purchased ATC-3 leak test unit.

3.0 Short Term Project Activities

3.1 STP Phase I Tasks

3.1.1 Feasibility of Production/System Integration (Task 3.3.1.1)

Pressure Method

The Pressure Inspection method and the Vacuum Inspection method were studied for integration with the Horizontal Form-Fill-Seal (HFFS) production line.

A laboratory test unit from Container Integrity Corporation (CIC) was used to establish feasibility of integrating the Pressure Inspection method with the HFFS production line. A number of factors were evaluated such as cycle time, machinery vibration and control of channel dimensions; suitability of sensors, irregular shape of filled pouches and required test pressure.

The location of the inspection equipment was determined to be immediately after the sealing station and before the punching section. This location is necessitated by the required channel

between adjacent pouches. The HFFS machine would be modified with an additional section consisting of lifting mechanisms, inspection equipment tooling, sensors, associated hardware and controls. The estimated cost of equipment was $300,000 per production line.

Benchtop tests were made to establish operating parameters and suitability within the production environment; air pressure, channel width, machine vibration, cycle time and tolerances for pouch misalignment.

Vacuum Method

Several meetings were held with Packaging Technologies & Inspection (PTI, formerly Wilco Precision Testers) to discuss the MRE pouch application. PTI specializes in inspection systems using the vacuum technique. Multiple chamber leak testers have been built for production line applications. Initial tests with a vacuum leak tester from PTI detected leaks and some contaminated seals. Integration of a vacuum leak tester with the MRE line is feasible at several locations; after the HFFS, after retort or after cartoning.

Interphex USA, held March 28-30, 1995 at the Javits Convention Center in NY, is the largest pharmaceutical manufacture and packaging exposition in the US. Interphex was a valuable opportunity to identify relevant technology and meet with experts. Ten companies exhibited leak detection equipment, four of which offer leak detection equipment for pouches; Benthos (TapTone), Mocom, Nikka-Densok USA and Packaging Technologies and Inspection.

3.1.2 Define System Design Requirements (Task 3.3.1.2)

System requirements for the CIC on-line tester are governed by Tiromat HFFS production limitations. The Tiromat running at the design rate of 102 pouches per minute in the present 6 pouch per index configuration has a total cycle time of 3.5 seconds. The dwell portion of the cycle (2.5 seconds) is available to seal inspection. An evaluation of the CIC test cycle indicates that the available time is inadequate for seal inspection. Since the method was abandoned, no further design requirements were developed.

Pouch defects were defined as follows:

1. pin holes 150 and 300 micron
2. cuts 1/8 inch long
3. channel leak across seal
4. contaminated and weak seal

Detection of seal wrinkle creep defects are not feasible by either pressure or vacuum method.

3.1.3 Component Requirements (Task 3.3.1.3)

Component requirements established for CIC tests but approach abandoned.

3.1.4 Drawings and Specifications (Task 3.3.1.4)

Functional requirements for leak detection equipment for leak detection equipment have been established; detection of pin hole leaks, channel leaks and weak seals due tocontamination. Functional requirements along with those of our (USDA) facility constitute the equipment

specifications.

3.1.5 Management Review

A review of project status with PO/COTR was held January 19, 1995. STP 21 status of Phase I Feasibility of Integration, Appendix 4.9, recommended proceeding with vacuum leak detection equipment.

3.2 STP Phase II Tasks

3.2.1 Fabrication and Assembly (Task 3.3.2.1)

PTI was contracted in November 1994 to design, build special chamber tooling for the MRE pouch and test. The tooling was completed in February 1995. Initial testing began at PTI prior to moving the unit to CRAMTD during March with the unit being operational at CRAMTD in April 1995 for pilot plant testing.

The ATC-3 unit was leased for a two month period, becoming operational at CRAMTD in May 1995.

3.2.2 Testing/Debugging (Task 3.3.2.2)

PTI

Initial tests of the Wilco unit at Packaging Technologies & Inspection (PTI) of Tuckahoe, NY indicated pin hole defects were found, however weak/contaminated seals were not detectable. The unit was shipped to the CRAMTD pilot plant to continue testing with a large number of sample pouches. Tests focused on establishing equipment operating parameters.

Modifications were made to the chamber tooling to improve detectability. A problem with plugging of pin holes was attributed to the chamber design and a plastic mesh was added to the contact surfaces to provide channels for gas to escape. Further testing of the unit is needed to optimize the chamber design and establish accuracy and cycle time.

The Wilco tester was evaluated with MRE pouches in various combinations of product (ham slice, beef stew, franks, water, and empty), residual gas and defect (hole, hole locations and contaminated seal). A number of pouches were tested to establish best machine operating parameters; fill=2.0 sec., equalize=0.1 sec. and test=4.0 sec. The Wilco unit uses 2 criteria for leak determination; reference pressure of the chamber at the completion of filling and pressure change (ΔP) during the test time. These values were established for each pouch configuration based on a statistical analysis of good pouches. Failure to reach the reference pressure indicates a gross leak, a moderate to large ΔP indicates a small hole.

A second chamber tool was built by PTI made of a rubberized flexible membrane which forms to the contours of the MRE pouch, further reducing the volume of the test chamber. This modification was intended to improve the sensitivity of the unit. It is unclear whether there was an improvement with this tool since holes located on the top or bottom of the pouch were mostly undetectable due to hole plugging. A plastic mesh was added to the chamber providing channels for the leaking air to pass. Results improved for pouches containing fluid.

ATC

The ATC-3 is a leak tester from Applied Technology Concepts, Inc. (ATC) of Towaco, NJ. The ATC-3 chamber was modified with a flexible membrane similar to the Wilco unit to reduce chamber volume. System sensitivity was severely degraded and the unit was returned to the original configuration. Further testing with the unit included pouches in cartons and a variety of products. The data was being reviewed for possible modification to the programmed detection algorithms.

Pilot plant evaluation of both leak test units were completed in July 1995, results are contained in Appendix 4.7. These tests made direct comparison of the Wilco and ATC units under identical conditions. Pin hole defects were made with a 150 micron diameter needle at four areas of the pouches; top/center, top/edge (near corner), bottom/center and bottom/edge (near corner). Weak/contaminated seals were produced by smearing salad dressing on the pouch seal area.

3.2.3 Documentation (Task 3.3.2.3)

Results of performance tests for the PTI tester and ATC tests are contained in Appendix 4.7.

3.2.4 Pilot Validation QA Benefit (Task 3.3.2.4)

A test was conducted at AmeriQual Foods on September 5-6, 1995, to verify CRAMTD pilot plant results. Two products were tested; chicken stew pouches taken from the production line and grilled chicken breast taken from warehouse inventory. The Chicken Breast pouch leaks were detected at the same accuracy (in and out of the carton) as the Ham Slice pouches tested at CRAMTD. The test on pouches taken from AmeriQual production failed to duplicate the conditions and results of prior tests at CRAMTD. Differences between AmeriQual and CRAMTD production methods accounted for the difficulty:

- hot fill method - product flashes at moderate vacuum level
- steam flush evacuation - negligible residual gas, typically less than 1cc
- low defect rate - 1 actual leaking pouch in approximately 80,000 produced, abrasions are more common
- leaks are usually punctures and can occur at any point of production

3.2.5 Workshop/Demonstration (Task 3.3.2.5)

In response to concerns regarding a high defect rate of MRE pouches due to leaks, DPSC has committed resources to assist the MRE producers reduce rejected pouches. A workshop at CRAMTD was held on August 22nd with representatives from DPSC and 6 suppliers in the MRE program to review the results of leak test equipment evaluated at CRAMTD. The agenda is included as Appendix 4.10.

4.0 Appendix

4.1 Figure 1 - CRAMTD STP #21 Time & Events and Milestones

4.2 Pressure Differential Techniques for Package Integrity Inspection

4.3 CIC CA2000 Leak Detector

4.4 Vacuum Leak Test Equipment Suppliers

4.5 Wilco Vacuum Leak Tester

4.6 ATC-3 Electronic Leak Tester

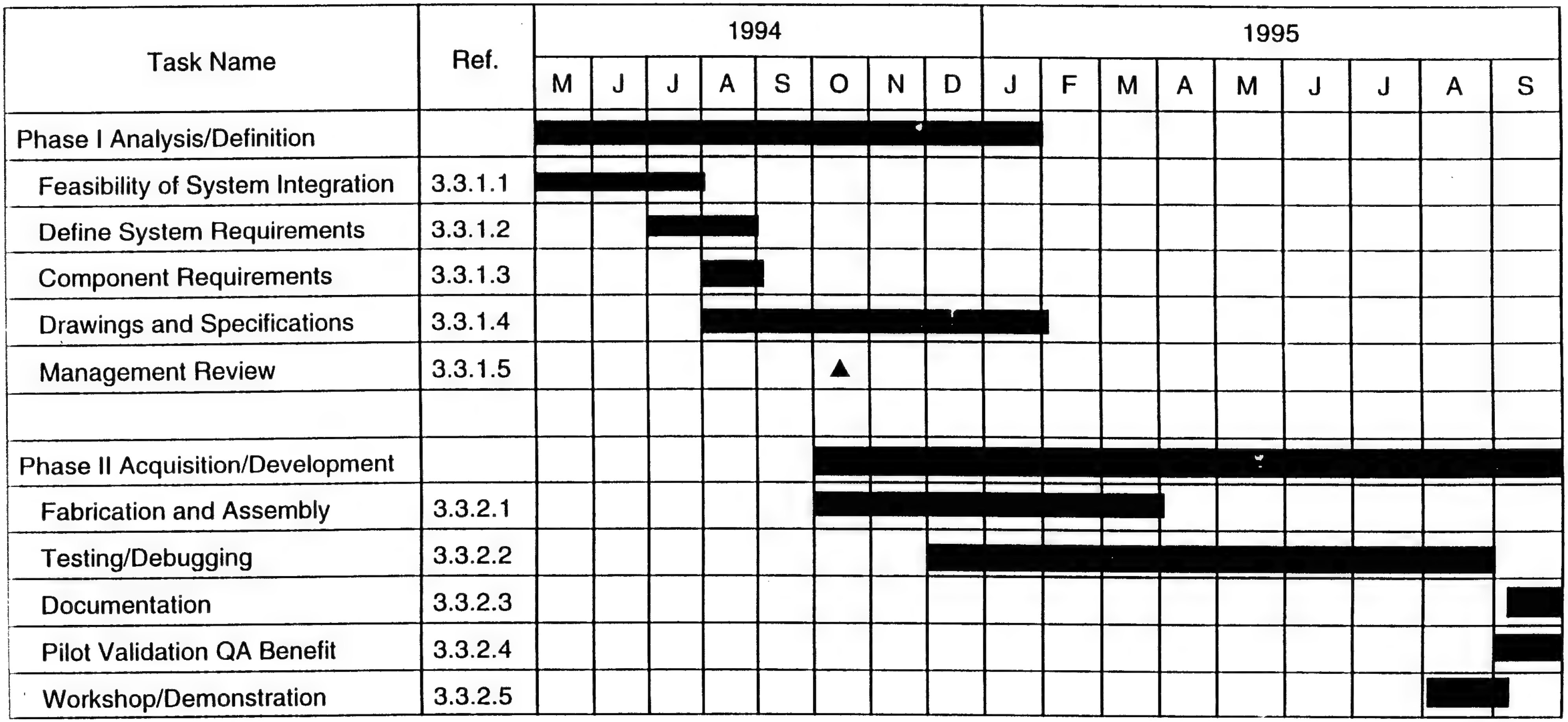
4.7 Performance Tests: PTI and ATC

4.8 Benchmarks for ATC-3 Leak Test Unit

4.9 Status - Non-Destructive Prototype to Inspect MRE Pouch seal Integrity - Phase I, Feasibility of Integration /System Requirements

4.10 Agenda for Flexible Pouch Package Integrity Initiative Meeting, August 22, 1995

Figure 1 - CRAMTD Short Term Project #21
Prototype Seal Integrity Inspection
Projected Time & Events and Milestones



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PLASTIC PACKAGE INTEGRITY TESTING

ASSURING SEAL QUALITY

BARBARA A. BLAKISTONE, PH.D
CAROL L. HARPER, PH.D

EDITORS

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CHAPTER SEVENTEEN

PRESSURE DIFFERENTIAL TECHNIQUES FOR PACKAGE INTEGRITY INSPECTION

Kit L. Yam

ABSTRACT

This paper discusses the pressure differential techniques for inspecting leaks and weak seals. Vacuum and external pressure techniques are compared. An on-line, nondestructive system for inspecting leaks and weak seals for MRE pouches is described.

INTRODUCTION

The two major defects of food packages are leaks and weak seals. Presently, those defects are inspected using off-line methods such as the burst test and the dye penetrant test, which are labor intensive, slow, costly, and destructive. There is a need to develop techniques that are on-line, nondestructive, and cost effective. The existing techniques for inspecting package defects include the uses of pressure differential, heat, vision, ultrasonics, and so on. Among them, pressure differential techniques are the most popular.

The purpose of this paper is to discuss the principles and practical considerations of applying pressure differential techniques to inspect leaks and weak seals. A design of an on-line, nondestructive system for inspecting package integrity of military MRE (Meals, Ready-to-Eat) pouches is illustrated as a case study.

Leaks

There are two common types of leaks found in food packages: pinholes and channel leaks (Figure 1). The locations where pinholes and channel leaks may occur are the body and the seal area of the package, respectively. A channel leak has a much longer depth and is more difficult to detect than a pinhole. As the leak diameter decreases, the inspection becomes more difficult and costly. Presently it is not economically viable to perform 100%, on-line inspection for extremely small leaks. The most important consideration in the design of an inspection system is to determine the minimum size of channel leak that must be detected. Although microbes are as small as 0.2 µm, it is highly debatable whether detecting leaks of this size is necessary, especially for channel leaks. The arguments against such a

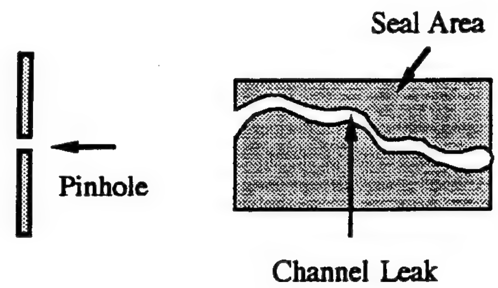

Figure 1
Pinhole and channel leak.

need are as follows. First, it is hard to believe that extremely small channel leaks (say, smaller than 80 μm) can be created due to defects such as wrinkles and food contamination in the seal area. Most real-life channel leaks are "huge," having diameters of at least 100 μm. Second, it is unlikely that microbes will penetrate very small leaks under ordinary conditions. Although biotest studies seem to indicate that microbes can penetrate channel leaks as small as 10 μm, the validity of the biotest is questionable because subjecting food packages to the extremely hostile environment of the biotest is a gross exaggeration of the real situation. Based on experience, it is the author's and several other experts's opinion that an inspection system can provide sufficient safety assurance if it detects pinholes of 10 μm and channel leaks of 50 μm in diameter

Principles of Leak Detection

Most leak inspection systems are based on a stimulus-response technique (Figure 2). There are three important components: a stimulus, a food package, and a response. For example, a stimulus for a pressure differential technique may be the application of pressure or vacuum to a package, and a response may be package movement or pressure change.

Besides leak sizes, other important considerations in designing a leak-detection system are sensitivity, speed, and cost. Sensitivity refers to the minimum leak size the system can detect. Speed refers to how much time is required to perform the inspection, which is often only a few seconds per package for on-line applications. Cost refers to the economic viability of the system. Both sensitivity and speed are functions of the stimulus, the package, and the response. For pressure differential techniques, sensitivity and speed can be increased by increasing the pressure driving force and/or by using a more sensitive sensor.

Weak Seals

Lampi et al. (1976) described four techniques for evaluating the seal integrity of MRE pouches—the fusion test, internal burst test, tensile test, and visual examination. Other techniques for inspecting MRE pouches are the dye penetrant test and bond strength test. Although these techniques are effective for determining the soundness of pouches, they are destructive (except for visual examination), time consuming, and labor intensive.

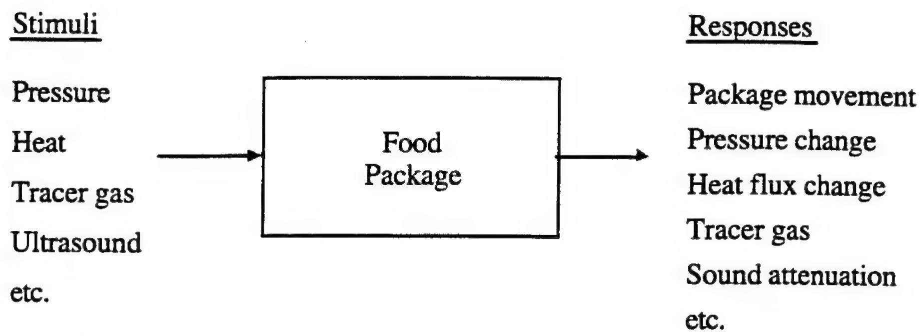

Figure 2
Principles of leak detection.

The internal burst test for pouches is described here because a variant will be discussed later. When conducting this test, a pouch is sandwiched between two parallel restraining plates, a needle punctures the top of the pouch wall, and compressed air is injected into the pouch at a predetermined rate (Figure 3). The military specification requires that MRE pouches should be able to withstand 20 pounds per square inch gauge (psig) for 30 seconds (s) when the restraining plates are 0.5 inch (in.) apart.

The pouch will rupture if the pressure is allowed to exceed a certain limit, which is called the burst pressure. Yam et al. (1993) have recently showed that the burst pressure P_b, the seal strength S (the force per unit width required to pull the seal apart), and the half-plate separation R are related by

$$S = P_b R \tag{1}$$

If S is kept constant, P_b is inversely proportional to R. Thus, if 20 psi is required to rupture the pouch when the restraining plates are 0.5 in. apart, only 10 psi is required when the restraining plates are 1 in. apart. Equation (1) suggests that various levels of forces could be applied on the seals by adjusting the pressure and the plate separation.

PRESSURE DIFFERENTIAL TECHNIQUES

Basic Principles

When pressure differential exists across the wall of a package, a possible leak will cause a test gas (such as air or nitrogen) to flow in or out of the package. An observed gas flow is an indication of a leak or leaks. There are two common methods for detecting gas flow: (1) by measuring pressure changes using a very sensitive pressure sensor, and (2) by measuring deflections of the package wall caused by the gas flow using a proximity sensor (Stauffer 1988).

Leak rates Q may be estimated using a simplified equation

$$Q = \frac{A}{L\ R} \Delta P \tag{2}$$

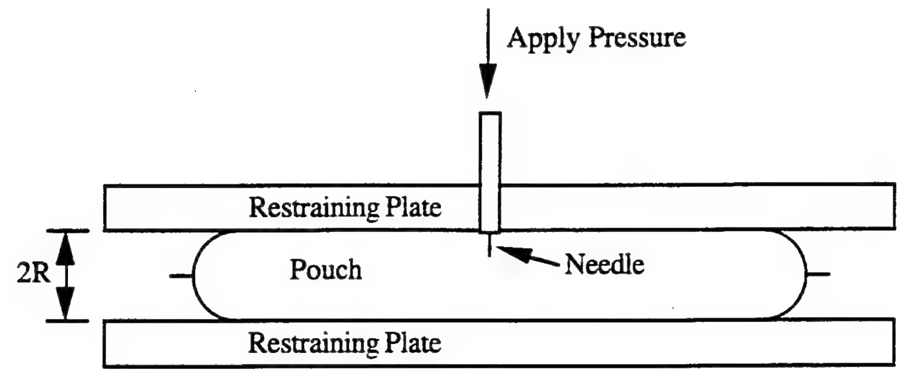

Figure 3
Internal burst test.

where A is effective cross-sectional area, L is effective length, R is resistance, and ΔP is pressure differential. The term "effective" is used because pinholes and channel leaks often have irregular shapes and tortuous paths. R depends on the test gas and the package material. Equation (2) suggests that the leak rate increases as A or ΔP increases, or as L or R decreases. A common unit for leak rate is cubic centimeters of gas (at standard temperature and pressure) per second or std cc/sec. Leak rate sometimes is used as a measure for the sensitivity of leak-detection systems; for example, the sensitivity for the bubble test is 10^{-4} std cc/sec; for the dye penetrant test, 10^{-6} std cc/sec; and for the helium mass spectrometer test 10^{-11} std cc/sec. The sensitivity required for MRE pouches is estimated to be between 10^{-5} and 10^{-6} std cc/sec.

The selection of a more accurate leak rate equation depends on the mode of gas flow (Bray and McBride 1992). For very fine leaks, the equations for capillary flow (Floros and Gnanasekharan 1992) are more appropriate than Equation (2). Figure 4A shows the flow rate of nitrogen gas through discs containing laser-drilled holes increases greatly with increasing pressure differential and hole size. Figure 4B shows the flow rate of nitrogen gas through capillary tube diameters of approximately 100 μm. It decreases with increasing tube length and decreasing pressure.

Vacuum Method versus External Pressure Method

Pressure differential techniques are classified into the vacuum method and the external pressure method. In the vacuum method, a package is placed inside an enclosed chamber where a vacuum is drawn to create a pressure differential across the package wall. Gas or liquid will flow out of the package because the pressure inside the package (at about 1 atmosphere) is higher than the pressure in the vacuum chamber. The vacuum method works well for packages containing dry product or for packages having well-defined headspaces. It can be used for detecting gross leaks (≥100 μm) and for testing seal strength. However it is not suitable for detecting smaller leaks, especially when the package contains a wet product. There are at least four problems with the vacuum method: (1) a certain amount of residual gas must exist in the package; (2) since the pressure differential ΔP is limited to about 1 atmosphere, the gas flow rate is usually too small to be detected

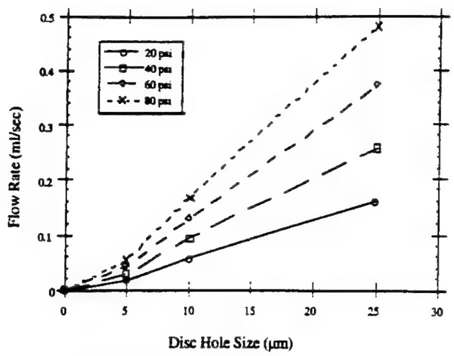

Figure 4A
Flow rate versus disk hole size.

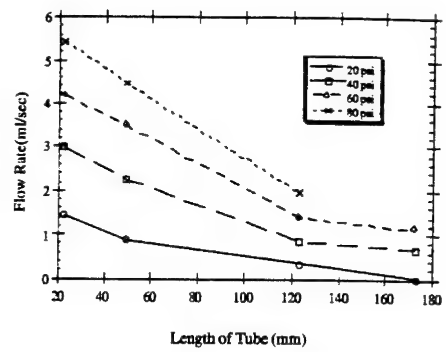

Figure 4B
Flow rate versus tube length.

rapidly; (3) the residual gas may be dissolved in the liquid food, which severely limits the mobility of the residual gas; and (4) any moisture inside the package may plug up leaks, making detection impossible.

The fourth problem is illustrated in Figure 5 where a liquid droplet is shown plugging up a channel leak. If the vacuum method is used, great resistance must be overcome before the liquid droplet is pushed through the channel leak. If external pressure is applied, the test gas can easily enter the package without having to push the liquid droplet through the channel leak.

In the external pressure method, the external pressure driving force causes the test gas to flow from the outside to the inside of the package. Again, the pressure inside the package is about 1 atmosphere, but the pressure outside the package could be much higher (say, up to 7 atmospheres). Compared to the vacuum method, this method does not require residual gas to be present in the package, requires shorter test time, and can detect smaller leaks.

The sensitivity of pressure differential methods varies widely (10^{-3} to 10^{-6} std cc/sec), depending on the magnitude of pressure differential, type of gas, time allowed for testing, shape and size of package, amount of residual gas, etc.

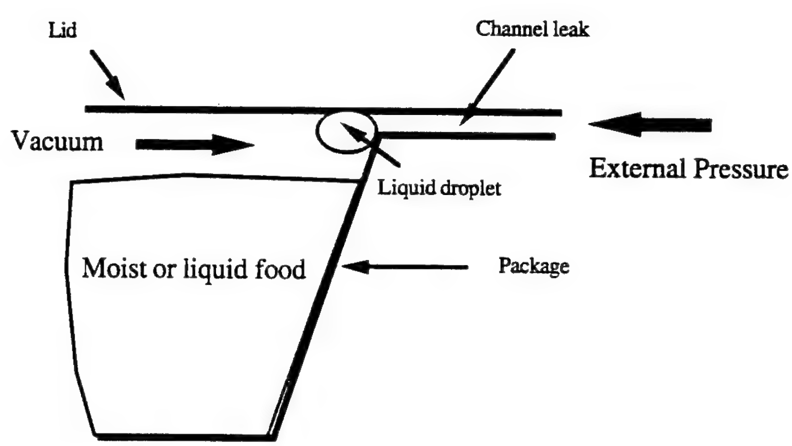

Figure 5
Leak plugged by liquid droplet.

CASE STUDY: AN ON-LINE MRE POUCH INTEGRITY INSPECTION SYSTEM

Combat Ration Manufacturing Facility

During the past several years, the Center for Advanced Food Technology (CAFT) at Rutgers University has been conducting a research program, entitled Combat Ration Advanced Manufacturing Technology Demonstration (CRAMTD), with an aim to develop, design, and assemble highly automated and flexible thermostabilization processes for manufacturing shelf-stable food products. A subproject of this program is to develop a high-speed, flexible, horizontal-form-fill-seal (HFFS) MRE pouch machine (Figure 6). The machine operates in an intermittent mode with a maximum throughput of 102 pouches per minute.

This new generation HFFS machine forms MRE pouches by shaping a roll stock of aluminum/plastics laminate (polypropylene/aluminum/polypropylene) into formed pouches (six pouches per index), followed by filling of food and heat sealing with a lid stock. The depth of the pouches is obtained by stretch forming the laminate into a cavity mold using a combination of air pressure, vacuum and/or plug assist. The HFFS pouch machine offers two attractive advantages compared to the traditional vertical-form-fill-seal (VFFS) pouch machines: (1) higher output, because the wider area allows faster filling, and (2) flexibility, because the machine can be easily converted to produce civilian packages such as plastic food containers. However, there is relatively little performance history on horizontal-filled pouches, compared to the vast information available for the traditional vertical-filled MRE pouches.

Described below is a design concept for developing an on-line, nondestructive system to inspect leaks and weak seals of MRE pouches produced by this HFFS machine. The system consists of two separate units. The first is a light sensor immediately after the forming station for detecting pinholes in formed pouches.

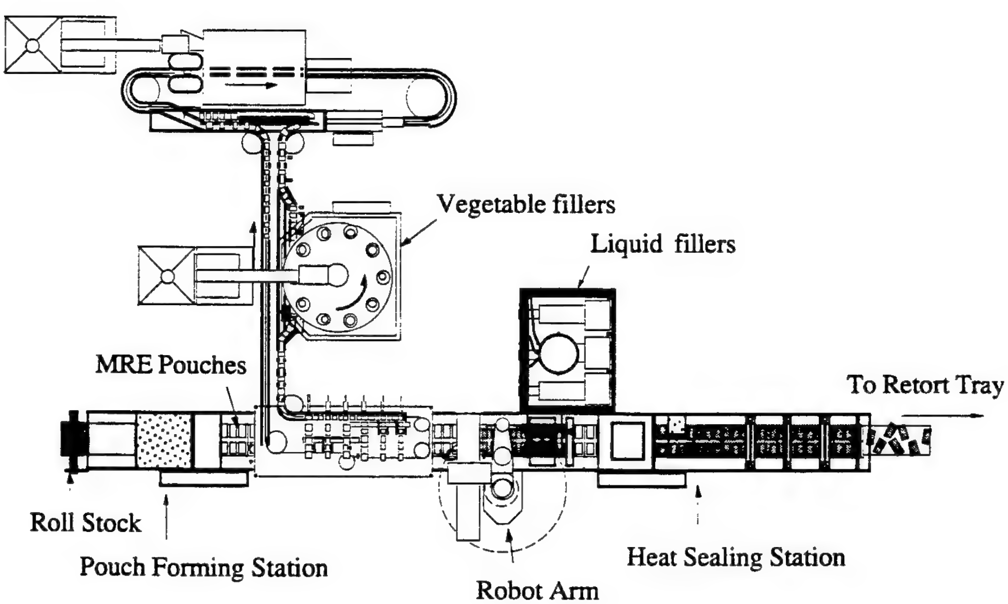

Figure 6
Horizontal form-fill-seal MRE pouch line.

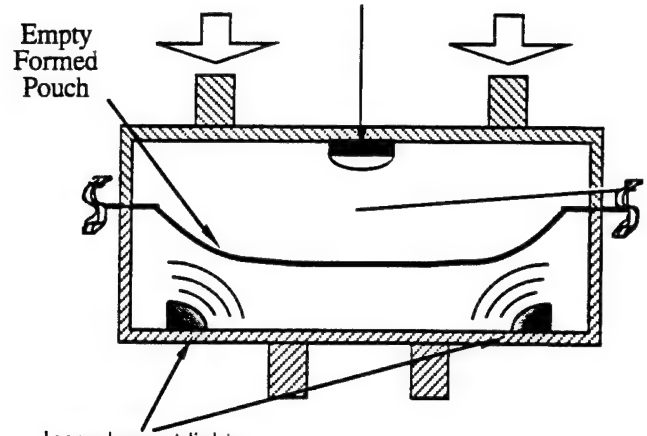

Figure 7
Light sensor unit.

The second is a pressure unit placed immediately after the sealing station for detecting channel leaks and testing seal strength (Figure 6).

Inspection of Empty Pouches

The existence of pinholes in vertical-filled MRE pouches is not considered to be a major problem. However, the stretch-forming of the newly developed HFFS operation may cause the film to break or form cracks, so checking for pinholes becomes a desirable or necessary step.

Pinholes in empty formed pouches can be detected rather easily with a light sensor (Figure 7). The unit is connected to a data acquisition system and is capable of detecting 10-μm pinholes in empty pouches or in lid stock within a second. Its sensitivity and response time are adequate for on-line application for MRE pouches. It is a relatively low-cost unit because only a simple data acquisition system and inexpensive light sensors are required.

Inspection for Sealed Pouches

After a pinhole-free pouch is filled with food and heat sealed, its seal integrity must be inspected. Figure 8 shows a concept of creating an open channel around the seal of a pouch in which compressed gas is applied. The open channel is created by using a clamping system. The first aim is to detect leaks in the seal. If there is a leak, the compressed gas will enter the pouch and cause its upper wall to move. The movement can be detected by a proximity sensor. A prototype of this concept has been shown to be able to detect 50-μm-diameter channel leaks within a few seconds.

The second aim is to use the open channel to perform a "nondestructive external pressure test" of the seal. If the seal is weak, the compressed gas will enter the pouch and cause the pouch wall to move. Note the similarity between the open

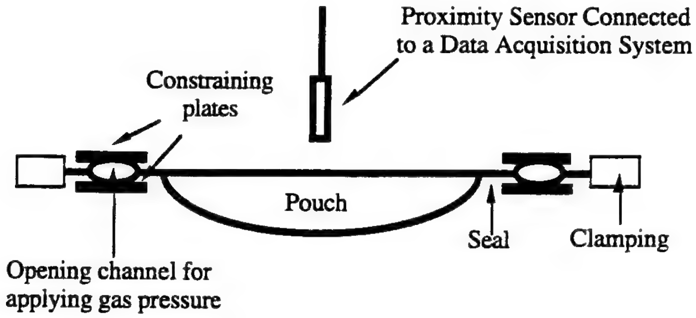

Figure 8
Concept for detecting leaks and testing seal strength.

channel and the internal burst test in Figure 3. The differences are that external pressure instead of internal pressure is used and the test is conducted nondestructively. Using Equation (1), the designer can use the gas pressure and the plate separation as independent variables to control the force applied to the seal.

Figure 9 shows an on-line application of the concept. It shows a section of the HFFS machine, operating in intermittent mode at six pouches per index. After heat sealing and cooling the seals, six pouches are moved to the inspection station where they are clamped. The clamping is designed to create an open channel around all the pouches. The channel can be inflated with compressed gas injected through a needle. If a leak or weak seal exists, the gas will enter the pouch and cause the pouch wall to move slightly. A proximity sensor located above each pouch detects any movement and sends a signal to a computer system for future action.

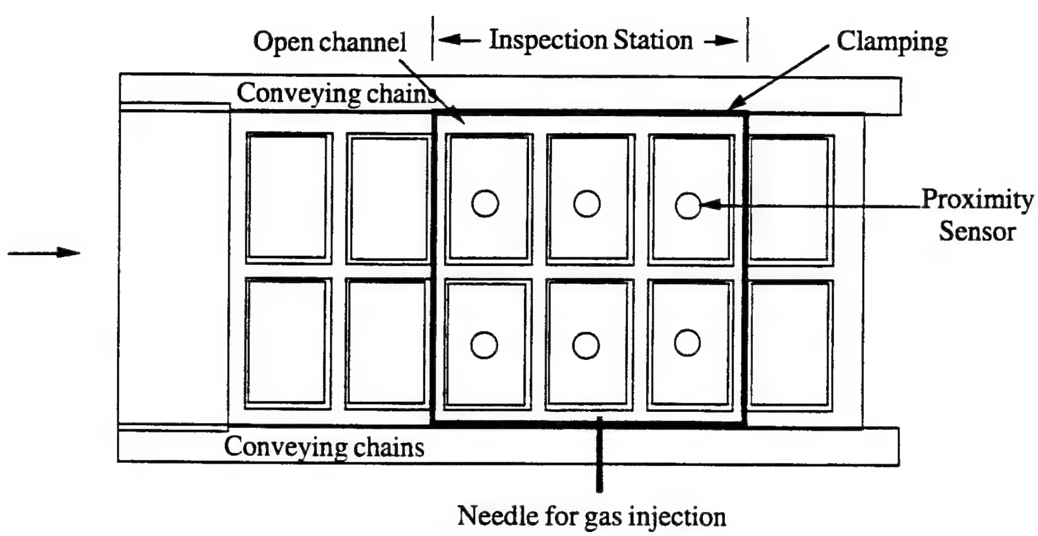

Figure 9
On-line leak and strength evaluation in an HFFS MRE pouch machine.

ACKNOWLEDGMENT

This work is funded by the Defense Logistics Agency through the Center of Advanced Food Technology (CAFT) at Rutgers University. The Center for Advanced Food Technology is a New Jersey Commission on Science and Technology Center.

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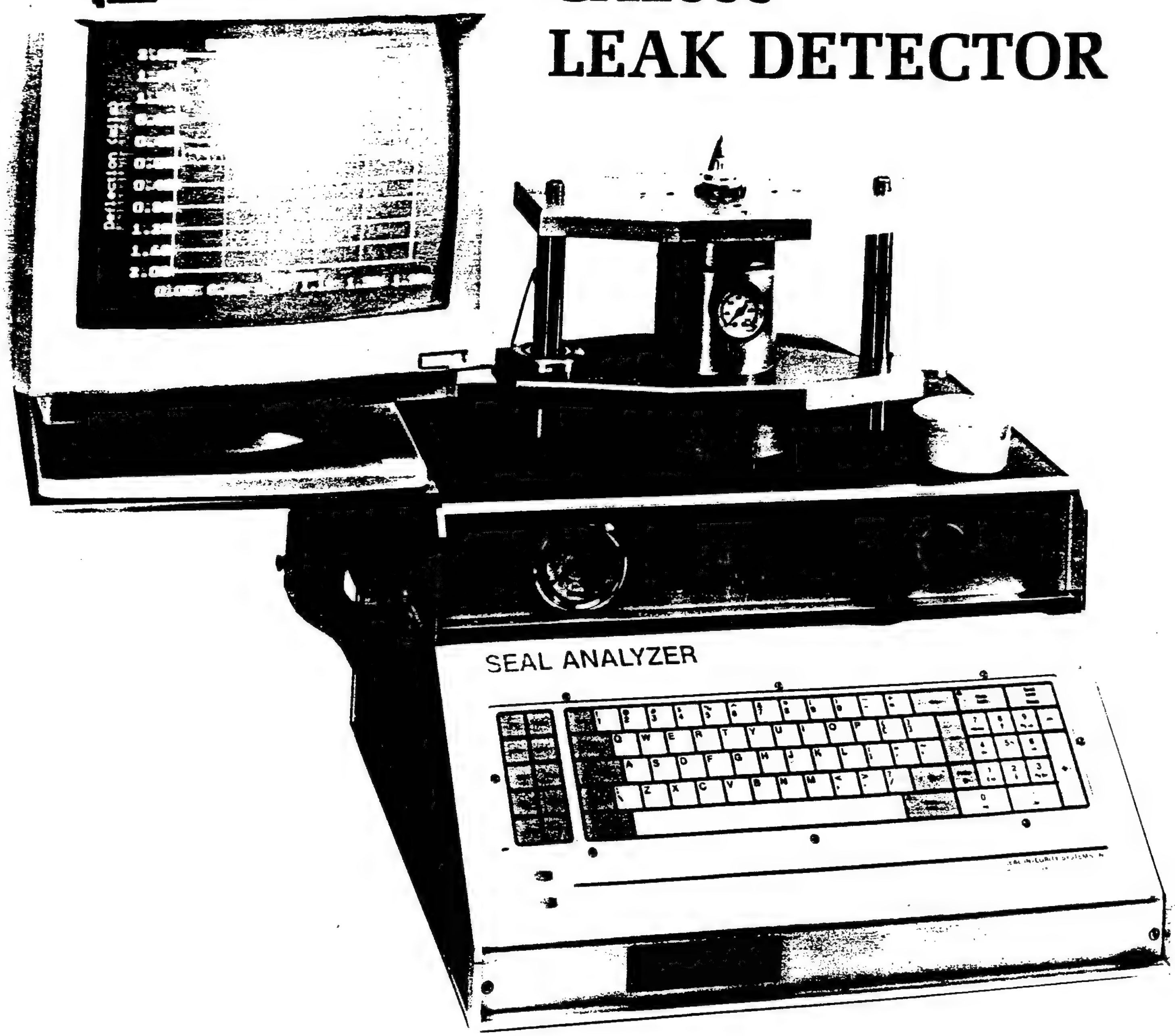
Appendix 4.3

INTRODUCING
THE NEW

CA2000
LEAK DETECTOR



SEAL OF INTEGRITY
PRESSURE TESTED
SEAL INTEGRITY SYSTEMS INC

A NEW CONCEPT IN MICRO LEAK DETECTION

CA2000

CA2000 PLASTIC CONTAINER TESTER uses high pressure gas, computer controlled electronics, and a patented container support structure to detect micron sized leaks in seconds.

CA2000 PLASTIC CONTAINER TESTER forces high pressure gas around the closure seal. If there is a leak, lid deflection will occur, a sensor will detect the defleciton and the CRT screen will say "BAD".

FEATURES

- User Friendly, Easy-to-Read Large CRT Color Screens display test results.
- Auto or Manual Mode: Auto mode allows you to pre-program for your specific test conditions. Manual allows you to start and stop the test at any time you desire.
- Adjustable Test Pressure (up to 150 psig).
- Test time is variable from .1 second to 4 hours.
- Certified Test Results: The operator can print out certified test reports with the use of any printer.
- Detects hole size down to 5 microns.
- Deflection Setting: You set the deflection limits on the Seal Analyzer to compensate for the sensitivity of different types of container lids.
- Modular Test Head Design allows the technician to switch sizes and types of containers in just minutes.
- The RS-232 Serial Port gives you an optional expandable memory allowing for storage of test results for analysis, statistical averages and permanent records.
- Nondestructive Testing.

SEAL OF INTEGRITY
PRESSURE TESTED
SEAL INTEGRITY SYSTEMS INC.

SEAL INTEGRITY SYSTEMS, INC.

618 The Parkway
Richland, Washington 99352
Phone: (509) 943-1189 Fax: (509) 943-0707

Vacuum Leak Test Equipment Suppliers

Nikka Densok U.S.A., Inc.
610 Garrison Street, Suite T
Lakewood, CO 80215
Attn: Brian Ball
303-202-6190, fax 303-202-6195

TM Electronics Inc.
330 Tacoma Street
Worcester, MA 01605
Attn: Dean Andrews
508-856-0500, fax 508-856-0548

ATEQ Corp.
42040 Koppernick Road
Canton, MI 48187
Attn: Stephen Neff
313-451-9449, fax 313-451-9462

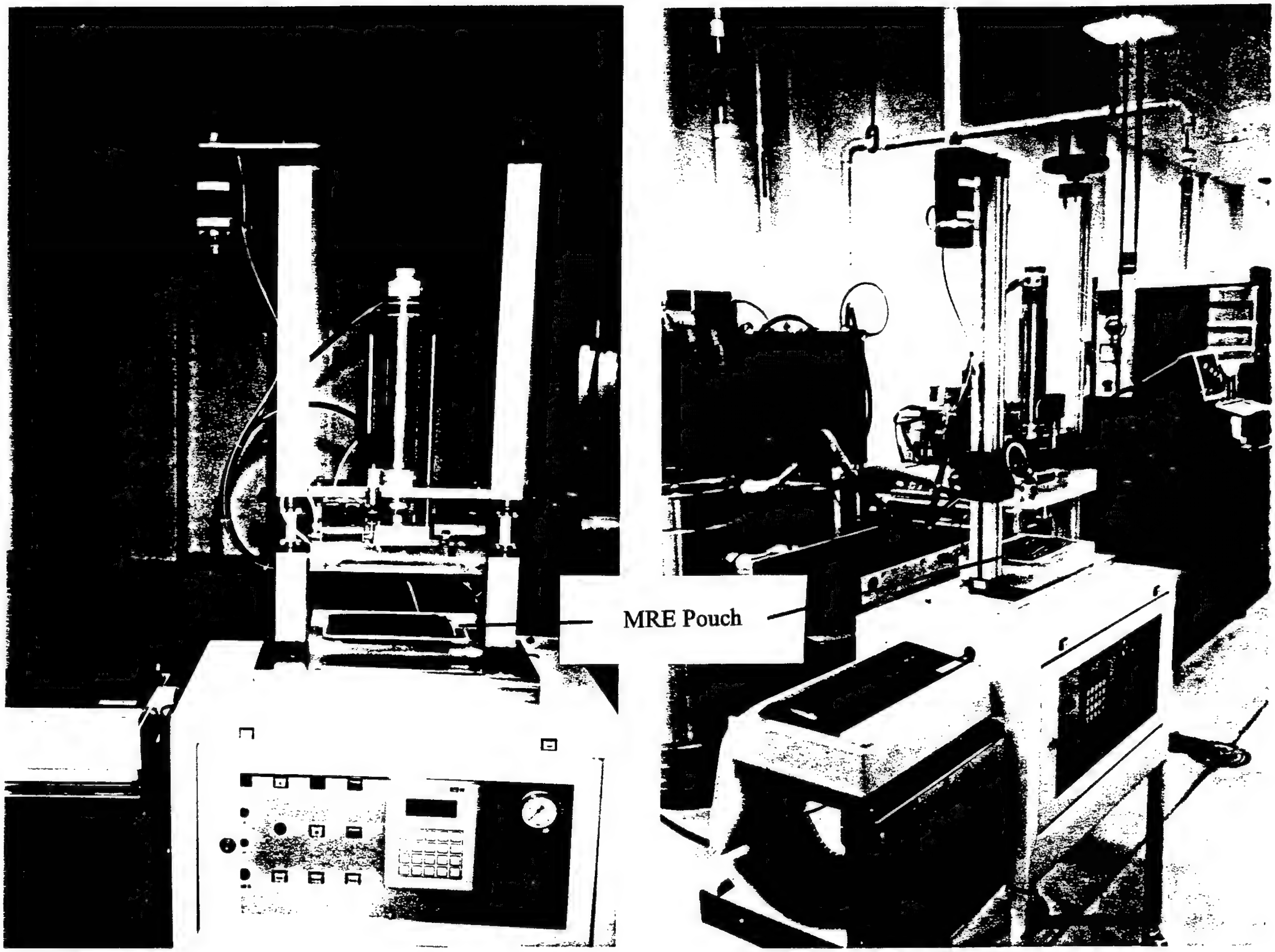
Applied Technology Concepts, Inc.
292 Brookvalley Road
Towaco, NJ 07082
Attn: Sami Halaby
201-492-9146

Packaging Technologies & Inspection
145 Main Street
Tuckahoe, NY 10707
Attn Tony Stauffer
914-337-2005, fax 914-337-8519

Non-package testers:
InterTech Development Co.
Forward Techology Industries, Inc.

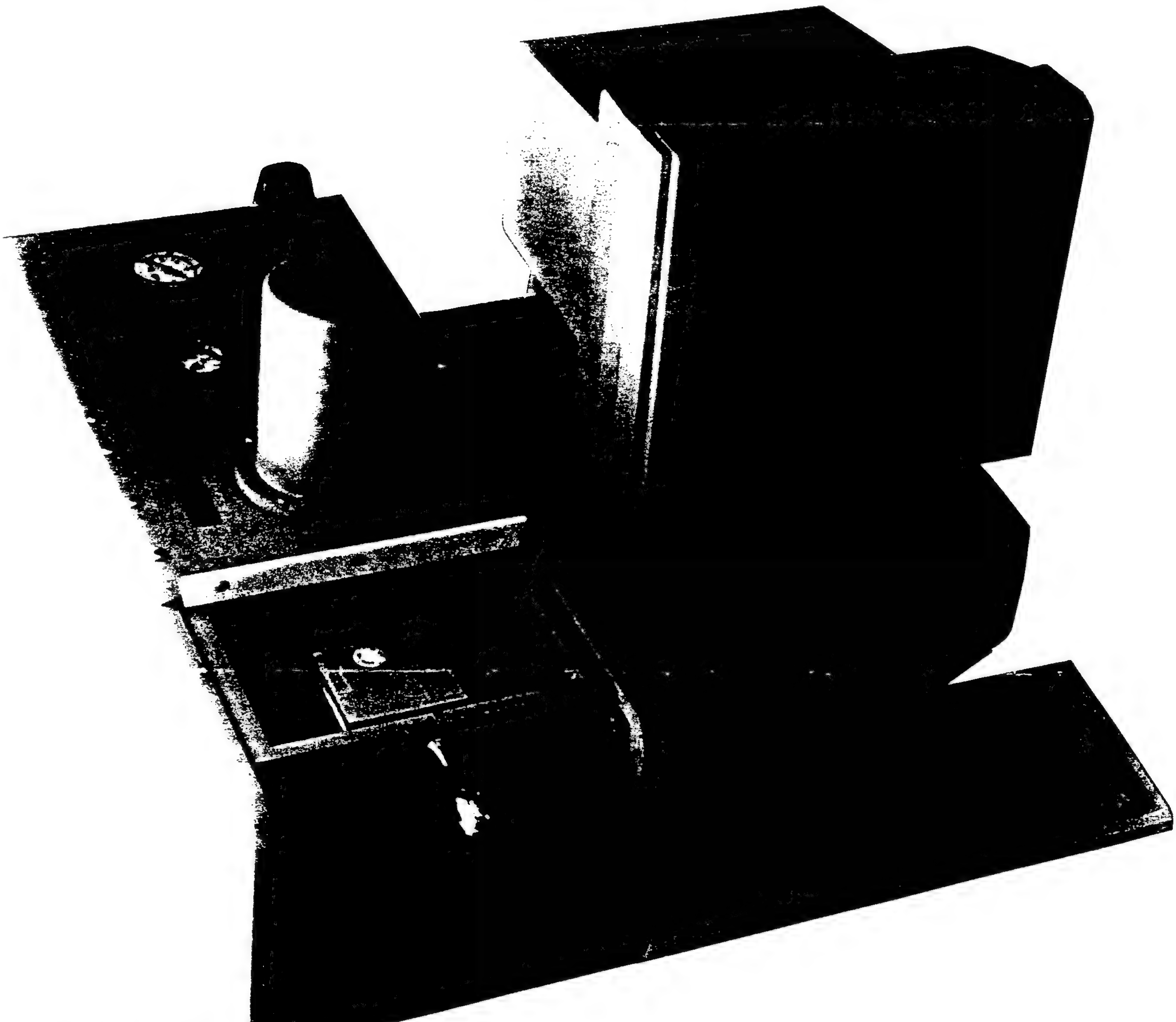
Pouch Squeezer:
Accu-Pak, Inc.

Wilco Leak Tester



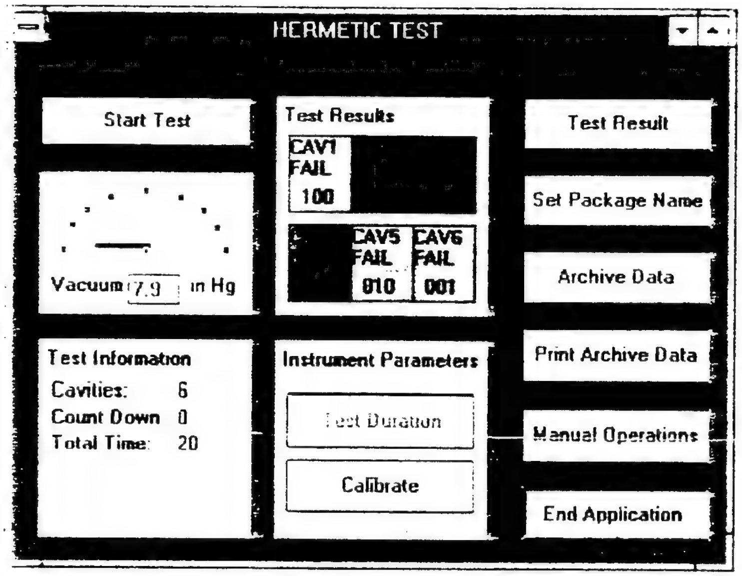
ATC-3 ELECTRONIC PACKAGE TESTER

- NON-DESTRUCTIVE LEAK AND SEAL TESTING ON A WIDE VARIETY OF PACKAGE DESIGNS
- CAN RECOGNIZE LEAKS OF 5 MICRONS OR LESS
- USES STORED PACKAGE PROFILES AND TEST PROTOCOLS
- AUTOMATICALLY RECORDS PHYSICAL DATA THROUGHOUT THE TEST CYCLE
- SIGNALS A CLEAR PASS/FAIL AND STORES COMPLETE RESULTS
- CAN BE CUSTOMIZED TO TEST SINGLE OR MULTIPLE SAMPLES
- TEST CYCLES UNDER THREE SECONDS PER SAMPLE ARE POSSIBLE



APPLIED TECHNOLOGY CONCEPTS, INC.

The ATC-3 system joins vacuum chamber mechanics and off-the-shelf Personal Computer technology with specialized application software. The mechanical side of the system is an airtight test chamber and a simple venturi vacuum pump. Vacuum and displacement transducers are used to acquire the physical test data that is passed electronically to the PC. The PC application presents graphic instructions and menus as shown below to guide the user through the steps to invoke the different modes of operation.



To conduct a typical test, a sample package is positioned in the test chamber, either manually or robotically, and the **START TEST** function is selected from the PC. All subsequent test steps are automated and under the control of the PC application. The chamber is evacuated to a pre-established pressure which is held constant until the test cycle is completed. The duration of the test is also preset, and will normally range between 15 and 45 seconds, although the system can be set up for any cycle time.

Throughout the test cycle, the PC application continuously monitors and records the chamber pressure and package expansion data acquired via the transducers. At the end of the test cycle, the PC application performs an analysis of the data that includes calculating several values which are compared with user established standards for the package being tested. A package which fails to expand a minimum amount, or which exhibits some expansion followed by contraction while under vacuum, is flagged as a leaker.

The ATC-3 brings a new level of quality assurance to product package testing. Samples can be tested "as is" on the packaging line: the sample is not destroyed and may be returned to finished goods or rework as test results indicate. The system is inherently accurate and repeatedly so, since the physical and mathematical principles which are its bases are well proven and because there are no package alterations necessary to enable testing. The software application approach to controlling the testing process allows the system to be tuned to the appropriate level of sensitivity, and by eliminating operator judgement, the system guarantees objectivity. Finally, as the ATC-3 is ruggedly constructed and has few adjustable components, it will operate with high reliability in extended use.

Operationally, the ATC-3 surpasses all other testing devices on the market. Since the system is controlled and managed via flexible application software, setup and calibration as well as sample testing becomes a simple matter of choices invoked from the PC display. The degree of programmed automation and simple mechanical construction combine in a system highly resistant to changes in adjustments and settings. Package handling is minimized and chamber geometry can be customized with removable fixtures for different packages and orientations to assist and speed up changeover to other products. Any number of test programs may be stored on the PC and called up on demand. As a stand alone system, the ATC-3 is almost totally automated, while at the same time portable. However, once again the simplicity of the hardware and mechanical operation allow the system to be easily integrated with robotics to perform package handling, thereby eliminating manual intervention altogether.

From a management viewpoint, the ATC-3 is truly leading-edge. It is a system that is currently being used by both the packaging development and manufacturing functions. A system initially used to support development of a new product package might then be implemented on the packaging line for the new package. Computer Integrated Manufacturing and Statistical Process Control depend on the availability of data spanning considerable production history. The ATC-3 includes functions to automatically archive test data and results which can be accessed by optional application software to conduct comprehensive statistical and quality analyses; and since the PC application system utilizes standard Information System components, the historical data can be readily passed to higher level decision support systems via common communication channels and busses.

APPLIED TECHNOLOGY CONCEPTS, INC
292 BROOKVALLEY ROAD TOWACO, NJ 07082-1034 (201) 492-9146

REPORT ON CRAMTD LEAK TESTS (6/28 - 6/30/95)

PERFORMANCE TESTS: PTI AND APPLIED TECHNOLOGY CONCEPTS

1. METHOD

Ham with No Vacuum

48 good ham pouches were produced with no vacuum (170cc headspace) and calibrated on the PTI leak tester. 40 of these pouches were subsequently pierced to create pinholes at 4 different locations (Top Center, Top Corner, Bottom Center and Bottom Corner). Each pouch was first tested on the PTI leak tester and then on the ATC-3 Electronic Package Tester (Applied Technology Concepts).

Ham with Vacuum

51 good ham pouches were produced under vacuum (5cc headspace). 40 of these pouches were pierced for pinholes at 4 different locations as described above. The remaining pouches were pierced and tested on the ATC equipment only. An extra 22 pouches were produced and contaminated by smearing salad dressing at different locations on the seal. Each pouch was then tested on the PTI leak tester and then on the ATC-3.

2. RESULTS

Table 1: Ham with No Vacuum (170cc)- Defects Positively Tested by PTI and ATC - 3

Defects	PTI	ATC
Pinholes		
Top Corner	10/10	10/10
Top Center	8/10	10/10
Bottom Corner	10/10	10/10
Bottom Center	10/10	20/20*

* Further tests done to optimize testing time.

Table 2: Ham with Vacuum (5 cc)- Defects Positively Tested by PTI and ATC - 3

Defects	PTI	ATC
Pinholes		
Top Corner	9/10	12/14
Top Center	0/10	13/15
Bottom Corner	8/10	13/15
Bottom Center	1/10	1/10
Contamination	8/22	0/22

3. DISCUSSION

3.1 Ham with No Vacuum

PTI

Good pouches were calibrated on two separate days (6/29 and 6/30) and the mean values and standard deviations for RP and DP were as follows (Appendix 1 to 4):

	Mean	S.D
R.P		
6/29/95	863.03	2.26
6/30/95	859.88	2.14
D.P		
6/29/95	273.28	17.23
6/30/95	248.92	10.22

Note:The flexible bladder has a natural leak of 200-300 Pascals when tested without product however it does not seem to affect the results.
All defective pouches were detected during the filling period (ie within 3 seconds) except for 2 pouches with a pinhole at the top center. In those two cases, the DP and RP were within the population range of the good pouches and were not detected (Appendix 5 and 6)
.

ATC

All defective pouches were detected. The time to detect was between 20 to 30 secs. The decision to fail is based on the expansion curve which calculates the deviation from a maximum point and compares the decrease in slope by linear regression over the last third of the curve to the vacuum curve. Even if the pinhole is blocked by product, the expansion curve will show a different profile from a good pouch. This is a similar concept as the load cell however the LVDT transducer is much more sensitive than a load cell.

3.2 Ham with Vacuum

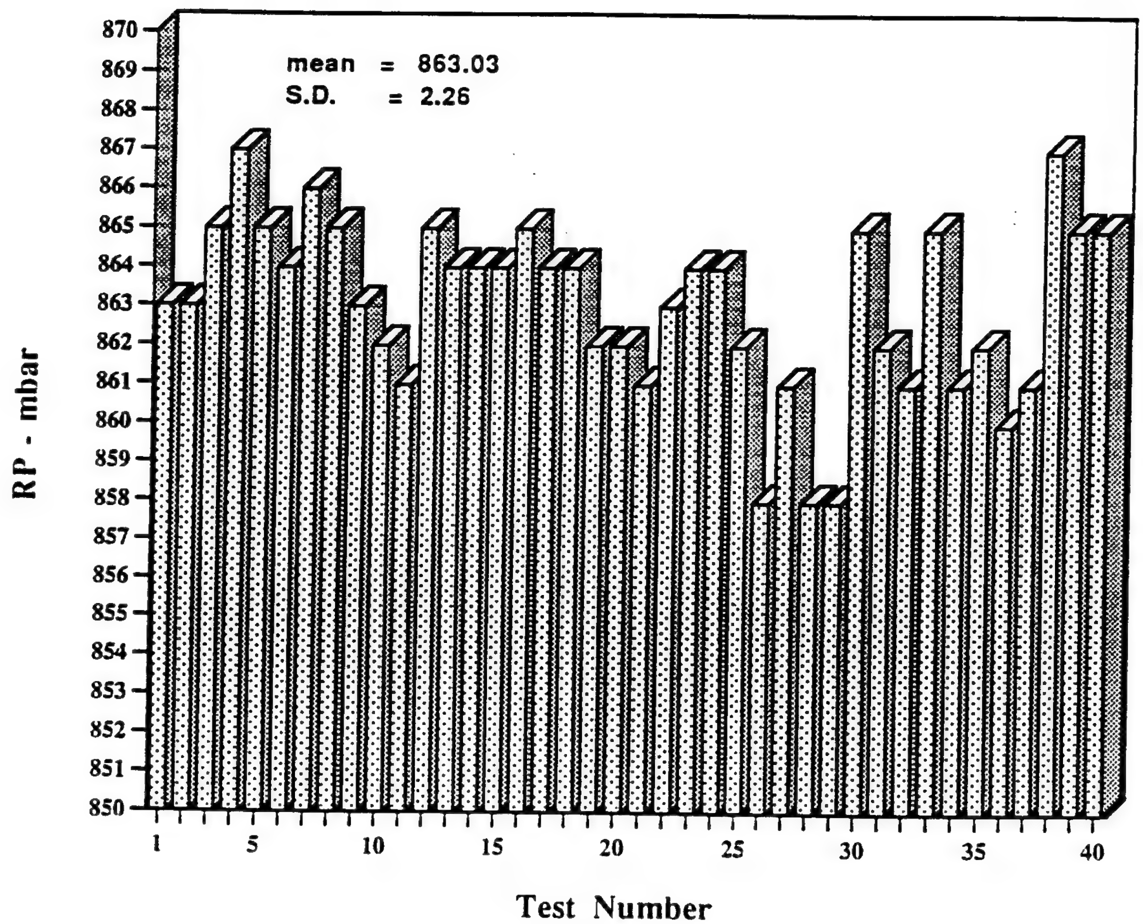
PTI
Good pouches were calibrated and the mean value and standard deviation for RP and DP are as follows(Appendix 7 and 8):

	Mean	S.D.
R.P	832.08	2.64
D.P.	367.10	22.79

Pinholes: Top Corner - 9/10 were detected. 8 during filling and 1 during testing
Top Center - 0/10 were detected, all RP and DP were within population of good pouches
Bottom Corner - 8/10 were detected during filling
Bottom Center - 1/10 detected during filling (See Appendix 9 and 10)

Contamination: 8/22 were detected. 4 during filling and 4 during testing. This suggests that seal contamination results in the formation of micro or channel leaks (See Appendix 11 and 12)

Appendix 1 :RP for Control (6/29/95) - Ham with No Vacuum (170cc)



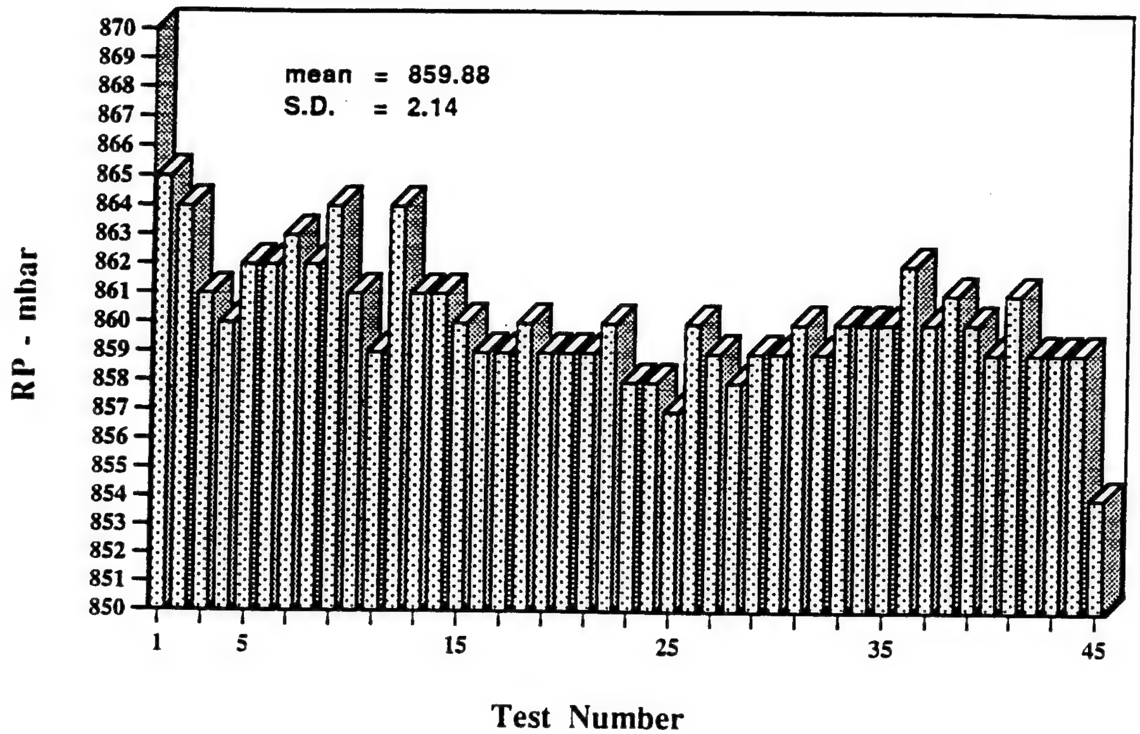
ATC

This tester can detect for pinholes consistently with the exception of pinholes at the bottom-center or contaminated seals.

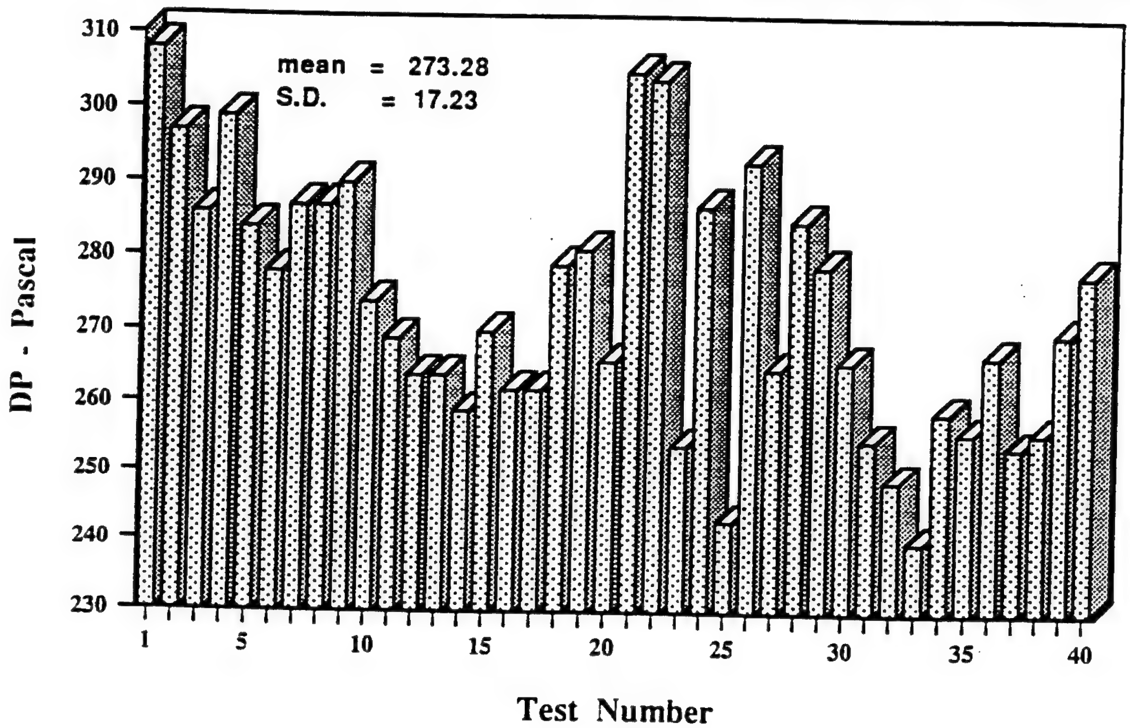
4. CONCLUSION

The Wilco tester has definite advantage in terms of response time, approximately 7 seconds versus the ATC tester which performed the leak test in 21-31 seconds. Both testers perform well when pouches have large headspace. The ATC test has a significantly higher accuracy for leaks in MRE pouches (5 cc headspace data).The ATC tester found 72% leakers versus 45% for the Wilco.

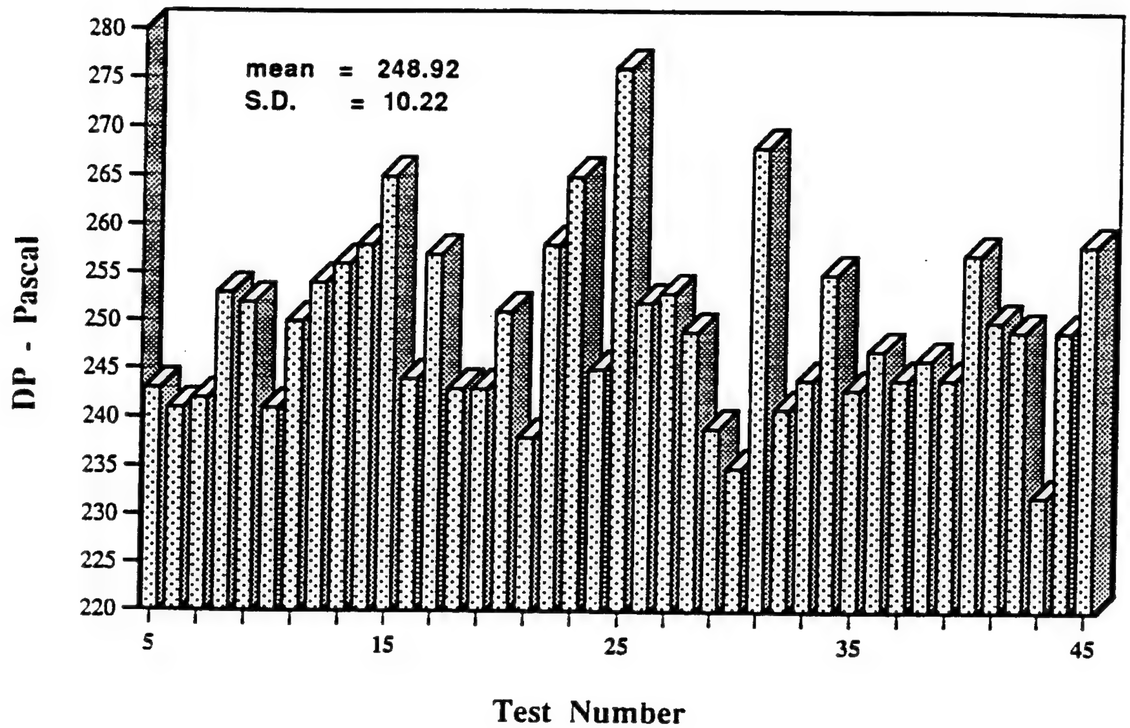
Appendix 2: RP for Control - Ham with No Vacuum (170cc)



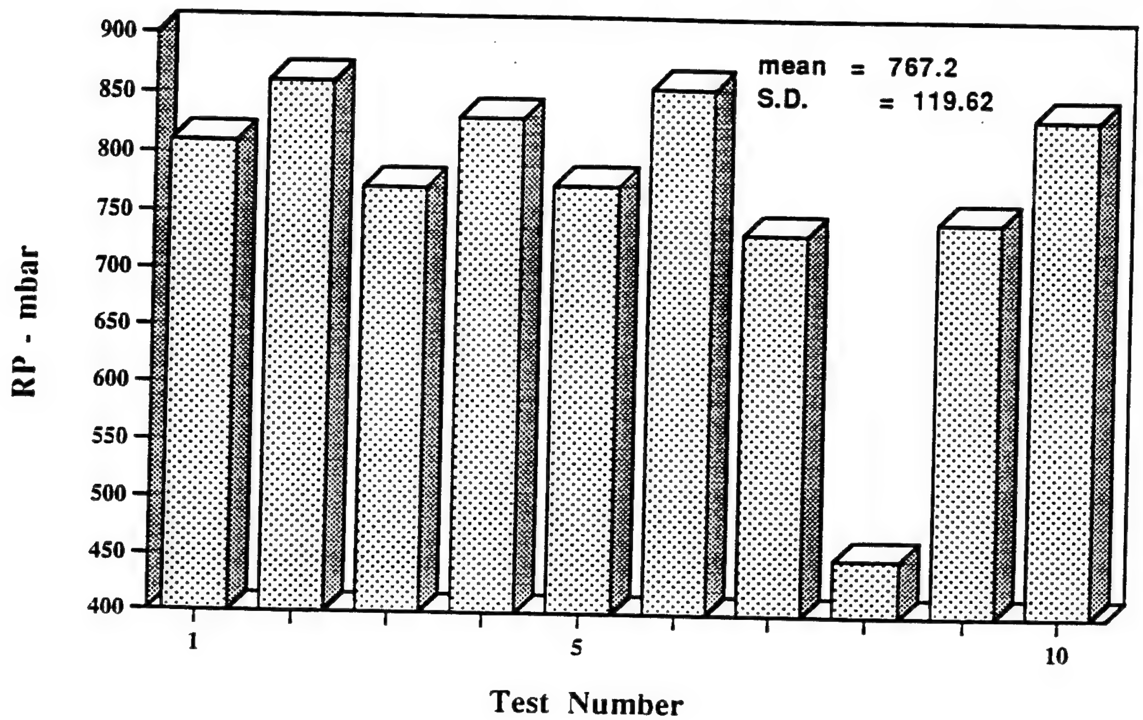
Appendix 3 :DP for Control (6/29/95) - Ham with No Vacuum (5cc)



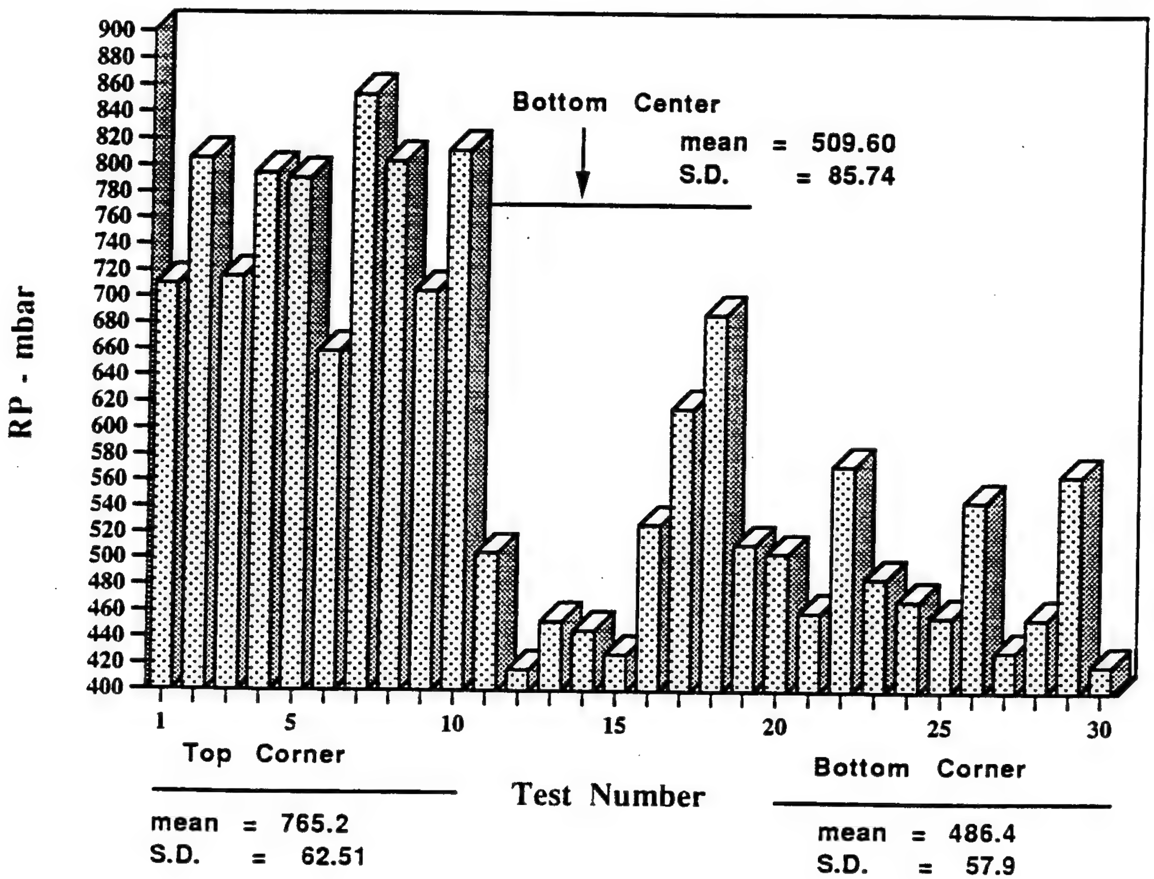
Appendix 4: DP for Control- Ham with No Vacuum (170 cc)



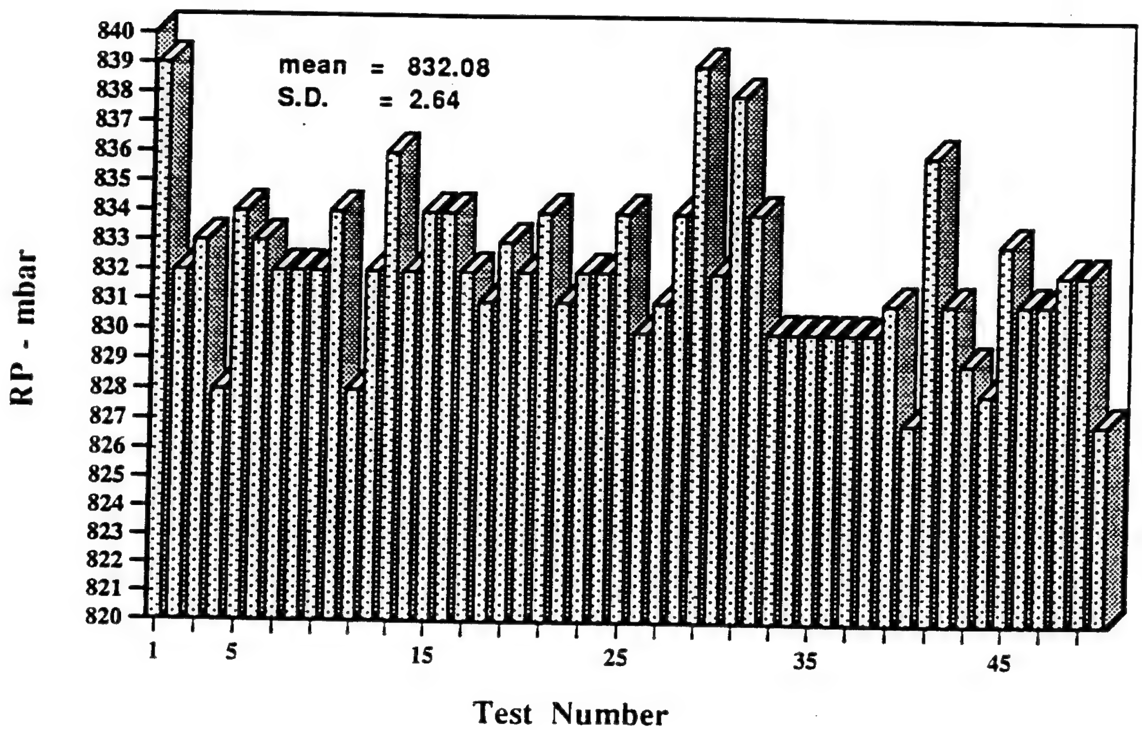
Appendix 5: RP for Pinhole (Top Center) - Ham with No Vacuum (170cc)



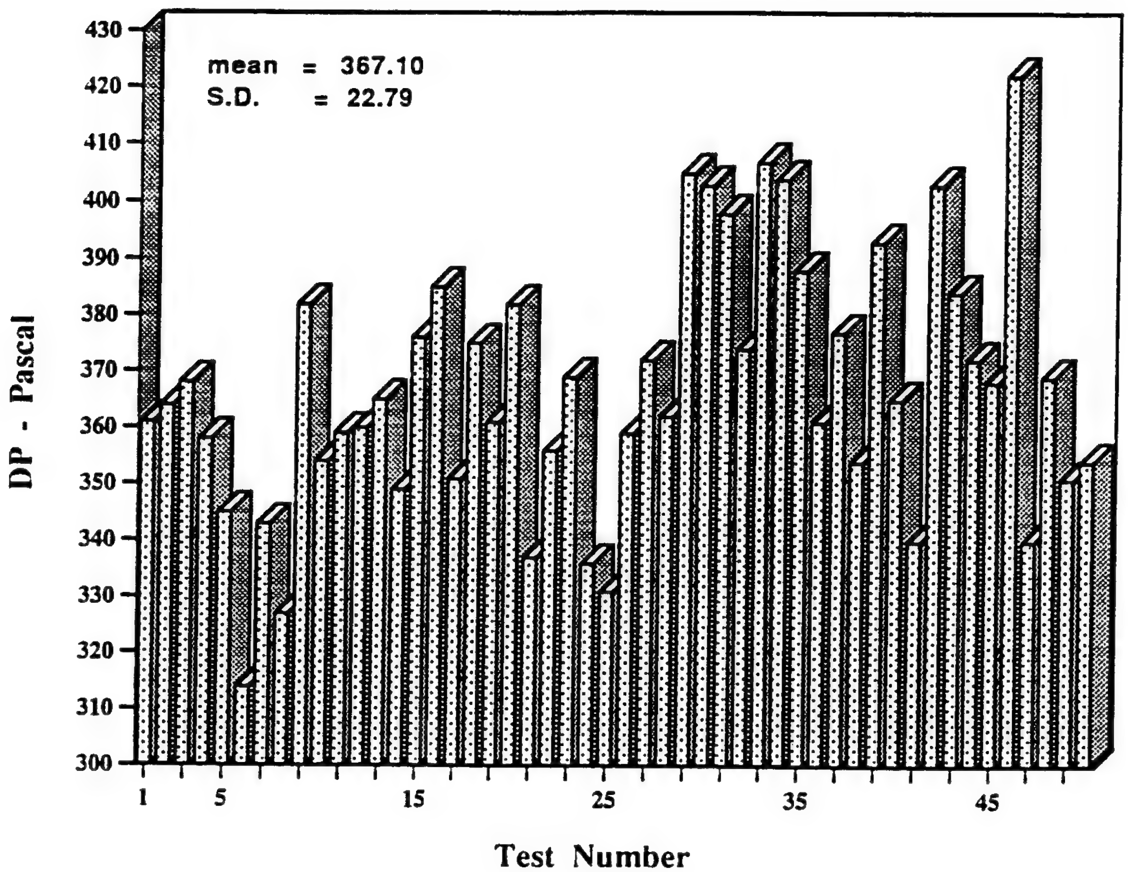
Appendix 6:RP for Pinholes (150 mic.) - Ham with No Vacuum (170cc)



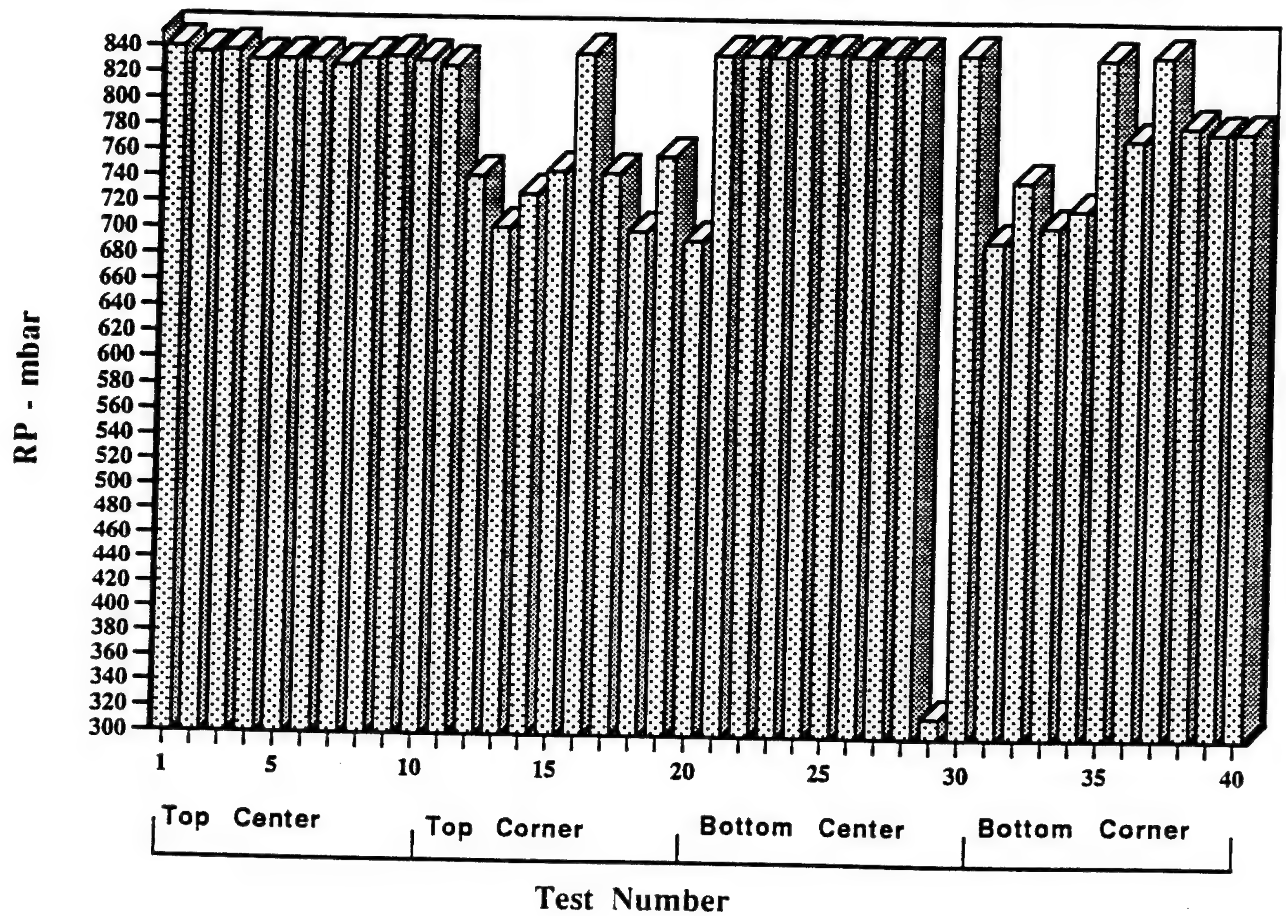
Appendix 7:RP for Control - Ham With Vacuum (5cc)



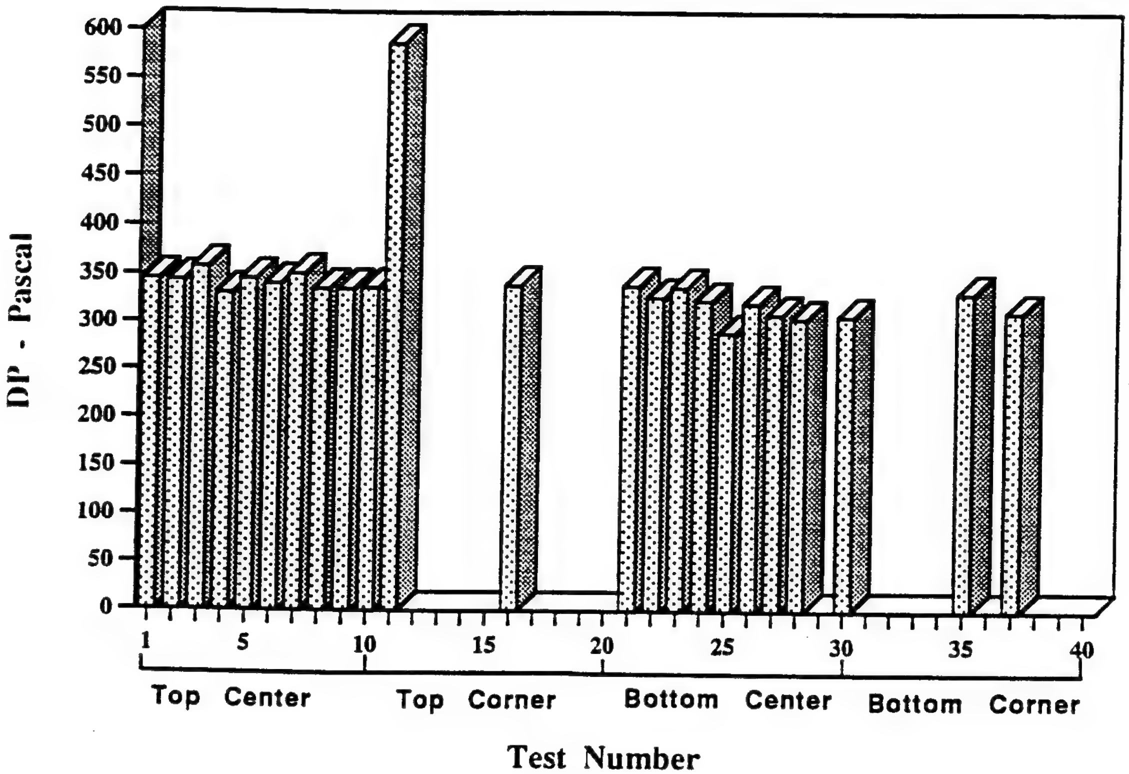
Appendix 8: DP for Control - Ham with Vacuum (5 cc)



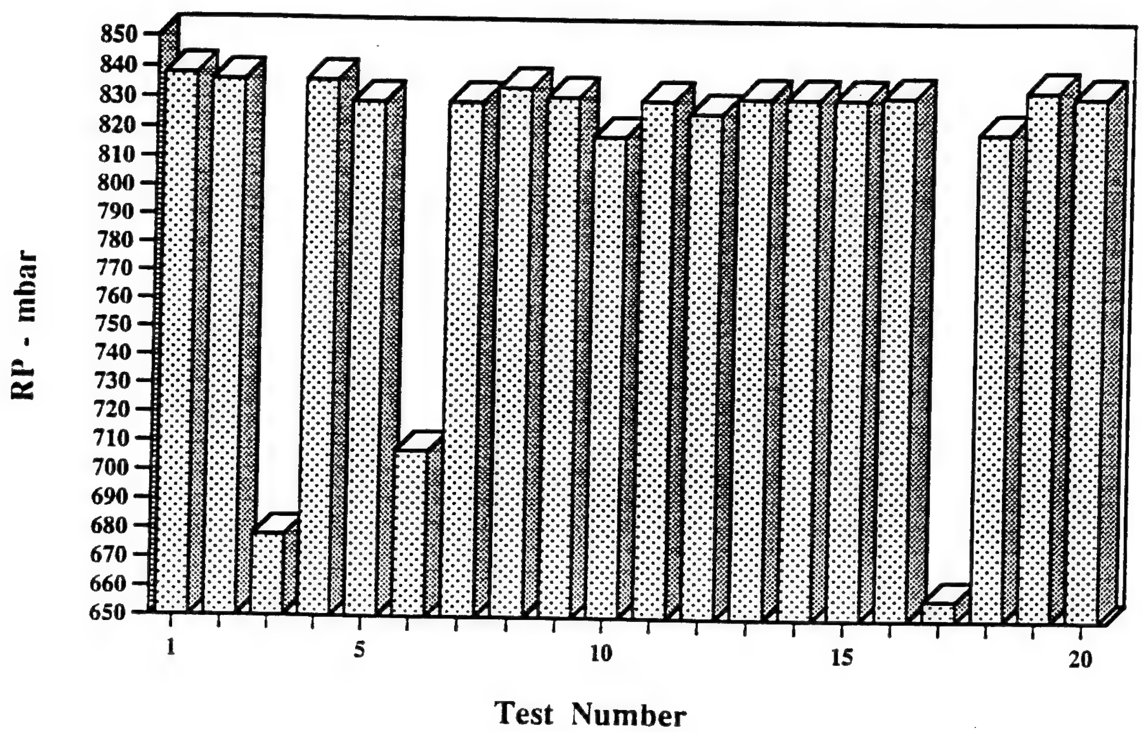
Appendix 9: RP for Pinhole (150 mic.) - Ham with Vacuum (5cc)



Appendix 10: DP for Pinhole (150 mic.) - Ham with Vacuum (5cc)

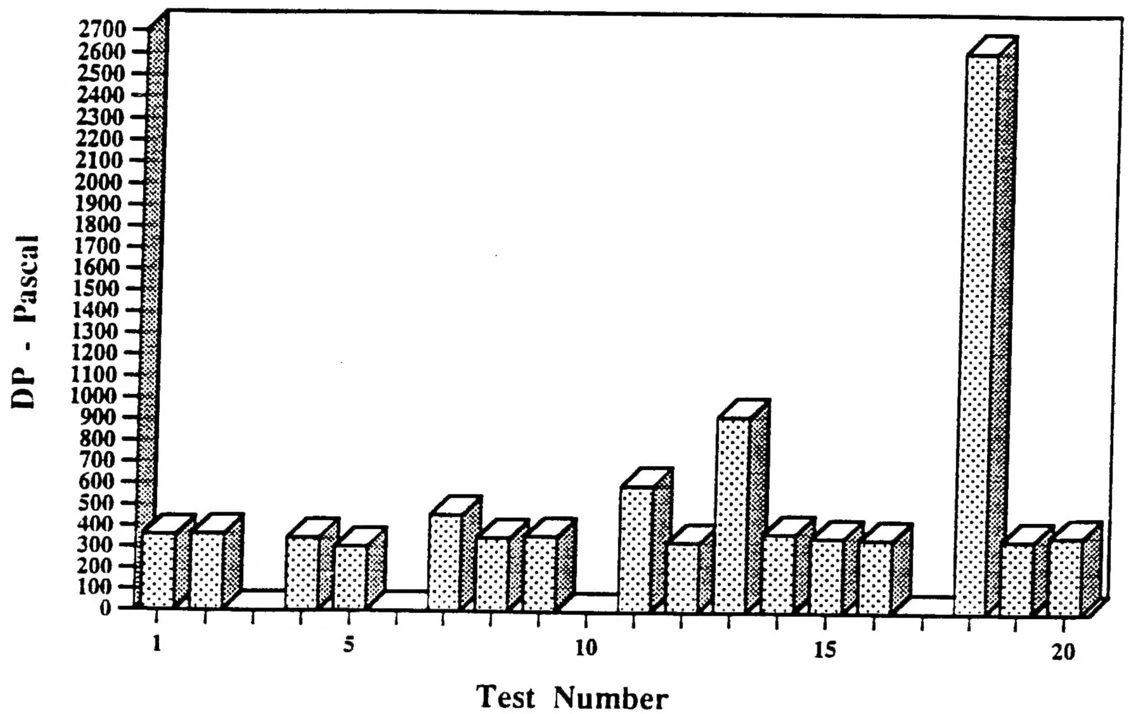


Appendix 11 :RP for Contamination - Ham with Vacuum (5cc)



mean = 809.73
S.D. = 53.27

Appendix 12 :DP for Contamination - Ham with Vacuum (5cc)



Benchmarks for ATC-3 Leak Test Unit

Product	Defect	Resid. Gas	Temp.	Accuracy	Test Duration
Ham Slice	150 micron hole	>25 cc	40 F	100%	20-30 sec
Ham Slice	150 micron hole	5 cc	40 F	72%	20-30 sec
Ham Slice	slit hole (.125 inch)	5 cc	40 F	88%	45 sec
Ham Slice	large hole	5 cc	40 F	88%	45 sec
Ham Slice in Carton	slit hole	5 cc	40 F	78%	45 sec
Beef Stew	150 micron hole	>25 cc	40 F	92%	15-20 sec
Beef Stew	150 micron hole	5 cc	40 F	54%	10-60 sec
Beef Stew in Carton	slit hole	5 cc	40F	ind.	45 sec
Chicken Stew	slit hole	1 cc	150 F	ind.	40 sec
Chicken Stew	slit hole	1 cc	94 F	ind.	40 sec
Chicken Breast	slit hole	7 cc	72 F	88%	40 sec

January 13, 1995

STP 21 Status - Non-Destructive Prototype to Inspection MRE Pouch Seal Integrity

Phase I, Feasibility of Integration/System Requirements:

HFFS Integrated External Pressure Method has a very high development risk

- Estimated cost high (>$300,000 per line) - higher than budget
- Slows production line rate
- Very high air pressures required (>200 psi)
- Warm seals may be difficult to see defects or may get damaged from test
- Irregular channel width between seals

Vacuum Method evaluation being conducted by PTI, results expected this month

- Units for on-line or off-line, before or after retort, civilian and military rations
- Will conduct test of vacuum unit at CRAMTD
- Estimated cost $40,000

Preliminary Conclusions:

- HFFS Integrated Pressure Method is difficult and costly for MRE, better suited for heat sealed trays or vertical pouch
- Off-line non-destructive Vacuum Method testing approach combined with process control will significantly increase assurance of defect-free MRE seals, the method can be used for either vertical or HFFS MRE production

Preliminary Recommendations:

- Purchase Vacuum Method single station test unit for plant floor QC if PTI results are favorable
- Propose STP for investigating off-line non-destructive inspection of polymeric half-steamtable tray
- Propose STP for investigating vision system for inspecting seal area prior to sealing

Flexible Pouch Package Integrity Initiative Meeting
August 22, 1995

Rutgers/CAFT Food Manufacturing Technology Facility
120 New England Avenue, Piscataway, NJ

Agenda

10:00 am	DPSC Initiative	C. Grabowski C. Viola
10:15	CRAMTD Programs	J. Coburn
10:30	Test Results	T. Descovich N. Litman
11:00	Leak Statistics	R. Bruins
11:15	Leak Tester Demo	T. Descovich N. Litman
11:45	Lunch	
12:30 pm	Producer Plant Operations Input Equipment Field Test	All
1:00	Statement of Work Draft	All
2:30	Wrap-up	C. Grabowski C. Viola J. Coburn
3:00 pm	Adjourn	

08/17/95